

# CAPACITOR FOR USE IN AN INTEGRATED CIRCUIT

## Cross-Reference to Related Applications

5           The present application is related to U.S. Patent Application Serial No. 09/838,526, filed 04/19/01, entitled "Capacitor for Use in Integrated Circuits," by R. Jacob Baker et al. and assigned to the same assignee as the present invention.

## Field of the Invention

10           The present invention relates generally to semiconductor integrated circuits, and more particularly to a capacitor and capacitor array for use in integrated circuits, such as memory systems and the like.

## Background of the Invention

15           There is a continuing demand for electronic systems to perform more functions or operations in shorter periods of time. This typically requires additional components to perform the additional functions and to store more programs and data. At the same time packaging requirements are decreasing in size. Consumers want smaller, lighter weight products that do more and are more mobile or portable.  
20   Accordingly, circuit designers are challenged to provide more components and greater capacity per unit of area on a semiconductor die.

          Most electronic circuits include basic electrical components such as transistors, resistors, inductors, capacitors and the like. Capacitors are one component that can occupy considerable area on a semiconductor die depending  
25   upon the size of the capacitor or the number of capacitors. For example, a memory system or device can include a large number of capacitors for storing information. Capacitors are typically made by depositing a first metal plate, depositing a layer of dielectric material over the first metal plate and then depositing a second metal plate over the layer of dielectric material and substantially parallel to the first metal plate.  
30   The size of the capacitance will be a function of the surface area of the two facing parallel plates and other parameters such as the dielectric constant of the dielectric

material and the spacing between the plates. Accordingly, one primary means of increasing the capacitance, is to increase the size of each of the parallel plates but this will also consume more area on the semiconductor die.

As previously mentioned, some electronic circuits, such as memory devices  
5 or systems use capacitors to store data electronically. For example, a capacitor with a charge on it can represent a logic 1 and an uncharged capacitor can represent a logic 0. Accordingly, as electronic systems or computer systems are required to perform more functions and to store more programs and data, memory devices and systems will require more memory cells with each cell including a capacitor to store  
10 the information. Memory device and system designers are therefore challenged to provide more storage capacity while using a minimum amount of area on a semiconductor die. For efficiency and speed of operation, the stored information is also preferably located close to those components that access and use the information. Accordingly, memory devices or systems are often formed on the  
15 same chip or semiconductor die with other components and it becomes important in the manufacturing process that the operations to make the different components are compatible and do not adversely effect one another and that the different components can be manufactured efficiently with the lowest possible cost and time.

Accordingly, for the reason stated above, and for other reasons that will  
20 become apparent upon reading and understanding the present specification, there is a need for a capacitor or an array of capacitors that maximizes the amount of capacitance and number of capacitors per unit of area of a semiconductor die or chip. There is also a need for a capacitor or capacitor array that can be manufactured efficiently with minimal process operations and with process  
25 operations that are compatible with or do not interfere with other circuitry or components formed on the same semiconductor die.

### **Summary of the Invention**

In accordance with the present invention, a capacitor includes a first plate of  
30 conductive material formed in a predetermined shape. A layer of dielectric material

is formed on at least a portion of the first plate and substantially conforms to the predetermined shape of the first plate. A second plate is formed over the layer of dielectric material.

In accordance with an embodiment of the present invention, a capacitor  
5 includes a layer of forming material and a nucleation layer formed on the layer of forming material. A substantially cone-shaped first plate of conductive material includes a vertex portion extending through the nucleation layer and partially into the layer of forming material. At least one of an interior surface and an exposed exterior surface of the first plate extending from the layer of forming material and  
10 the nucleation layer can be converted to hemispherical grains. A layer of dielectric material is formed on the nucleation layer and on the interior surface and the exposed exterior surface of the first plate. The dielectric layer substantially conforms to the shape of the first plate and the hemispherical grains. A second plate of conductive material is formed over the dielectric layer.

In accordance with an embodiment of the present invention, an array of  
15 capacitors includes a plurality of first plates of conductive material. Each first plate is formed in a predetermined shape with an open or hollow interior portion. A layer of dielectric material is formed on the plurality of first plates and substantially conforms to the shape of each of the first plates. A second plate of conductive  
20 material is formed over the layer of dielectric material.

In accordance with an embodiment of the present invention, a memory  
system includes an array of memory elements and each memory element includes a capacitor. Each capacitor comprises a first plate of conductive material formed in a predetermined shape. A layer of dielectric material is formed on at least a portion of  
25 the first plate and substantially conforms to the shape of the first plate. A second plate of conductive material is formed over the layer of dielectric material.

In accordance with the present invention, a semiconductor die includes a  
substrate and an integrated circuit formed on or supported by the substrate. The integrated circuit includes at least one capacitor. The capacitor includes a first plate  
30 of conductive material formed in a predetermined shape and a layer of dielectric

material formed on at least a portion of the first plate and substantially conforming to the shape of the first plate. A second plate of conductive material is formed over the layer of dielectric material.

In accordance with the present invention, an electronic system includes a processor and a memory system coupled to the processor. The memory system comprises an array of memory elements and each memory element includes a capacitor. Each capacitor includes a first plate of conductive material formed in a predetermined shape. A layer of dielectric material is formed on at least a portion of the first plate and substantially conforms to the shape of the first plate. A second plate of conductive material is formed over the layer of dielectric material.

In accordance with the present invention, a method of making a capacitor includes: forming a substantially cone-shaped first plate of conductive material; forming a layer of dielectric material on at least a portion of the first plate and substantially conforming to the shape of the first plate; and forming a second plate of conductive material over the layer of dielectric material.

In accordance with the present invention, a method of making a memory system includes: forming an array of memory elements; and forming a capacitor associated with each memory element. Forming each capacitor includes: forming a first plate of conductive material formed in a predetermined shape, forming a layer of dielectric material formed on at least a portion of the first plate and substantially conforming to the shape of the first plate, and forming a second plate of conductive material formed over the layer of dielectric material.

In accordance with the present invention, a method of making a semiconductor die includes: providing a substrate; forming an integrated circuit supported by the substrate; and forming a capacitor associated with the integrated circuit. Forming the capacitor includes: forming a first plate of conductive material formed in a predetermined shape, forming a layer of dielectric material formed on at least a portion of the first plate and substantially conforming to the shape of the first plate, and forming a second plate of conductive material formed over the layer of dielectric material.

In accordance with the present invention, a method of making an electronic system includes: forming a processor; and forming a memory system coupled to the processor. The memory system includes a plurality of memory cells and each memory cell includes a capacitor. Forming each capacitor includes: forming a first  
5 plate of conductive material formed in a predetermined shape, forming a layer of dielectric material formed on at least a portion of the first plate and substantially conforming to the shape of the first plate, and forming a second plate of conductive material formed over the layer of dielectric material.

These and other embodiments, aspects, advantages and features of the  
10 present invention will be set forth in part in the description which follows, and in part will become apparent to those skilled in the art by reference to the following description of the invention and referenced drawings or by practice of the invention. The aspects, advantages, and features of the invention are realized and attained by means of the instrumentalities, procedures, and combinations particularly pointed  
15 out in the appended claims.

### **Brief Description of the Drawings**

In the drawings, like numerals describe substantially similar components throughout the several views. Like numerals having different letter suffixes or  
20 primed (X') represent different occurrences of substantially similar components.

Figures 1A-1H illustrate the operations in forming a capacitor or an array of capacitors in accordance with the present invention.

Figure 2 is a top elevation view of a plurality of cavities formed in a substrate to form a capacitor array in accordance with the present invention.

25 Figures 3A-3C illustrate the operations in forming a capacitor or array of capacitors in accordance with an embodiment of the present invention.

Figure 4A-4C illustrate the operations in forming a capacitor or array of capacitors in accordance with another embodiment of the present invention.

Figure 5 is a block schematic diagram of a semiconductor die or chip including an integrated circuit and capacitor array in accordance with the present invention.

Figure 6 is a schematic diagram of a memory device or system including  
5 capacitors in accordance with the present invention.

Figure 7 is a top view of a wafer or substrate containing semiconductor dies in accordance with an embodiment of the present invention.

Figure 8 is a block schematic diagram of a circuit module in accordance with an embodiment of the present invention.

Figure 9 is a block schematic diagram of a memory module in accordance with an embodiment of the present invention.

Figure 10 is a block schematic diagram of an electronic system in accordance with another embodiment the present invention.

Figure 11 is a block schematic diagram of a memory system in accordance with an embodiment of the present invention.

Figure 12 is a block schematic diagram of a computer system in accordance with an embodiment of the present invention.

### **Description of the Embodiments**

20 In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other  
25 embodiments may be utilized and that process or mechanical changes may be made without departing from the scope of the present invention. The terms wafer and substrate used in the following description include any base semiconductor structure. Both are to be understood as including silicon-on-sapphire (SOS) technology, silicon-on-insulator (SOI) technology, thin film transistor (TFT)  
30 technology, doped and undoped semiconductors, epitaxial layers of a silicon

supported by a base semiconductor, as well as other semiconductor support structures well known to one skilled in the art. Furthermore, when reference is made to a wafer or substrate in the following description, previous process steps may have been utilized to form regions/junctions in the base semiconductor structure. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims.

The transistors described herein include transistors from bipolar-junction technology (BJT), field effect technology (FET), or complimentary metal-oxide-semiconductor (CMOS). A metal-oxide-semiconductor (MOS) transistor includes a gate, a first node (drain) and a second node (source). Since a MOS transistor is typically a symmetrical device, the true designation of "source" and "drain" is only possible once voltage is impressed on the terminals. The designations of source and drain herein should be interpreted, therefore, in the broadest sense. It should also be noted that a P-channel MOS transistor could alternatively be used for an N-channel MOS transistor and vice versa with the polarity of the associated gate voltages merely being reversed. For example, applying a negative gate voltage in the situation of a P-channel MOS transistor to activate the transistor and reversing the polarity to apply a positive gate voltage to activate an N-channel transistor if an N-channel MOS transistor is substituted for a P-channel transistor.

Figures 1A-1H illustrate the operations in forming a capacitor or an array of capacitors 100 in accordance with the present invention. In Figure 1A, a first layer 102 of forming material is deposited or formed. The first layer 102 of forming material can be a doped oxide or the like. A plurality of electrodes 104 can be formed in the first layer 102 of forming material by conventional photolithographic techniques. The electrodes 104 can have a selected pitch or spacing S between them. The electrodes 104 can be made of a metal or semiconductive material. A nucleation layer 106 can be formed on the first layer 102. The nucleation layer 106 can be formed from an undoped oxide or the like. A second layer 108 of forming material can be formed on the nucleation layer 106. The second layer 108 of

forming material can also be a layer of doped oxide or the like. The nucleation layer 106 can be much thinner than the first layer 102 of forming material and the second layer 108 of forming material can be much thicker than the first layer 102.

In Figure 1B, a plurality of openings or cavities 110 are formed in a surface 112 of the second layer 108 of forming material and in alignment with each of the electrodes 104. The cavities 110 are formed down through the second layer 108, the nucleation layer 106 and partially through the first layer 102 of forming material to expose a top portion 114 of each of the electrodes 104. The electrodes 104 serve as an etch stop to define the bottom of each of the cavities 110. The cavities 110 are formed to have a predetermined shape by standard photolithographic techniques and can have a depth dimension D much larger than a diameter or width dimension W. The predetermined shape of the cavities 110 can be substantially cone-shaped and can have a substantially elliptical or circular cross-section as shown in Figure 2.

In Figure 1C a first plate layer 116 of conductive material is deposited or formed on the surface of the second layer 112 of forming material and in each of the cavities 110. The first plate layer 116 can have a thickness of about 300 angstroms. The first plate layer 116 forms a predetermined shape corresponding to or conforming to the predetermined shape of each of the cavities 110 and the first plate layer 116 forms open or hollow interior portions or surfaces 118. The first plate layer 116 can be formed from a conductive metal, polysilicon or a semiconductor material.

Referring to Figure 1D and also to Figure 2, an isolation wall 120 can be formed around the capacitor array 100. The isolation wall 120 prevents the etchants or other materials used in the process operations to form the capacitor array 100 from adversely affecting or interfering with other components or integrated circuits already formed on the chip or die. The isolation wall 120 can be a photo mask or be covered by a photo mask to prevent or block etchants or other materials from contacting the other circuits or components on the chip. The



isolation wall 120 defines the capacitor array 110 and is preferably formed over the cavities 110 proximal to a periphery 122 of the capacitor array 100.

In Figure 1E, the first plate layer 116 is selectively removed from the surface 112 of the second layer 108 of forming material between the cavities 110 to form a plurality of first plates or first capacitor plates 126. A small segment of each first plate 126 can be removed from a small portion 124 of each of the cavities 110 near the surface 112 of the second layer 108. The first plate layer 116 can be selectively removed by dry etching with an etchant that is non-reactive to the second layer 108 of forming material.

In Figure 1F, the second layer 108 of forming material and the photo mask covering the isolation wall 120 are removed. The array 100 can be exposed to a cleaning process to remove the photo mask of the isolation wall 120. The second layer 108 can be removed by wet etching with an etchant that is non-reactive to the conductive material of the first plates 126. The first plates 126 can act as a mask in the process of removing the second layer 108 of forming material. The nucleation layer 106 can act as an etch stop or to at least slow down the etch rate so that it can be stopped at a predetermined depth Y. The first layer 102 of forming material is preserved to support the first plates 126. In an embodiment where a nucleation layer 106 is not used and there is only a single layer 102 of forming material, the etching process must be stopped so that a sufficient portion of the first layer 102 remains to support the first plates 126 during the remainder of the processing. Each of the first plates 126 have a predetermined shape that as shown in the embodiment of Figure 1F can be substantially cone-shaped including a vertex portion 128 or closed end extending through the nucleation layer (if present) and partially into the first layer 102 of forming material. Each of the first plate members 126 have an interior surface 118 or portion, as previously discussed, and an exposed exterior or outer surface 130 extending from the first layer 102 and the nucleation layer 106.

In Figure 1G, a layer 132 of dielectric material is formed on the nucleation layer 106 and on the first plates 126. The layer 132 will substantially conform to

the shape of the first plates 126 and will cover the interior surfaces 118 and exterior surfaces 130 of the first plates 126 exposed above the nucleation layer 106. The layer 132 can be a nitride, an oxide or a dielectric of any thickness. The undoped oxide of the nucleation layer 106 facilitates the nucleation or formation of the dielectric layer 132 on the nucleation layer 106 which permits the formation of a thinner layer of dielectric on the first plates 126.

In Figure 1H, a second plate 134 or second capacitor plate of conductive material can be formed on the dielectric layer 132. The conductive material of the second plate 134 can be a metal, polysilicon or a semiconductor material. The second plate 134 can be formed in bulk over the dielectric layer 132. After forming the second plate 134, the array 100 can be masked off and the peripheral areas of the die can be cleared back to the original level of material. The process of the present invention minimizes the step height H between the surface of the original level of the die and a top surface 138 of the second plate 134, thus creating a more desirable planar process.

The second plate 134 can be a common connection or ground connection for the capacitor array 100. Connection to each of the individual capacitors 136 can be made via the electrodes 104 which can be brought out to a peripheral edge 202 (Figure 2) of the capacitor array 100 for connection to transistors of a memory cell as discussed hereinbelow or to other components of an integrated circuit.

Referring to Figure 3A, in accordance with another embodiment of the present invention, after the process operations described with reference to Figures 1A-1F are carried out and the first layer 108 of forming material is removed in Figure 1F, if the first plates 126 are formed from polysilicon, the interior surfaces 118 of each of the first plates 126 can be converted to hemispherical grains (HSG) 302 by a standard technique. Converting to HSG 302 increases the capacitive area of each of the first plates 126 and thereby increased the capacitance of each of the completed capacitor cells.

In Figure 3B, a layer 304 of dielectric material similar to the dielectric layer 132 in Figures 1G-1H is formed on the HSG 302 of the first plates 126. The HSG

302 can be etched to remove micro fissures in the HSG 302 to provide a better surface for forming the dielectric layer 304 and so that the dielectric layer 304 can be thinner and thereby provide a higher capacitance. In Figure 3C, a second conductive plate 306 or second capacitor plate similar to the second capacitor plate 134 in Figure 1H is formed on the dielectric layer 304.

In accordance with another embodiment of the present invention shown in Figure 4A, the interior surface 118 and exposed exterior surface 130 of each of the first plates 126 (Figure 1F), if formed from polysilicon, can be converted to HSG 402 using a standard technique. The HSG 402 provide more capacitive surface area to each of the first plates 126 and hence added capacitance to each of the completed capacitor cells. In Figure 4B, a layer 404 of dielectric material is formed on the HSG 402 of the first plates 126. As previously discussed, the HSG 402 can have micro fissures and can be etched to provide a smoother, more uniform surface on which to deposit the dielectric layer 404. In Figure 4C, a second conductive plate 406 or second capacitor plate is formed on the dielectric layer 404.

Figure 5 is a block schematic diagram of a semiconductor die 500 or chip including an integrated circuit 502 and capacitor array 504 formed on a substrate 506 in accordance with the present invention. The capacitor array 504 can be the same as the capacitor array 100 discussed with respect to Figures 1A-1H or the capacitor arrays 300 and 400 in Figures 3A-3C and 4A-4C, respectively. Accordingly, the capacitor array 504 of the present invention can be formed on the same semiconductor die 500 or substrate 506 as the integrated circuit 502. As previously discussed, the second conductive plate 134 in Figure 1H (or second conductive plate 306 in Figure 3C and second conductive plate 406 in Figure 4C) can be a common electrode for the capacitor array 100 (or capacitor arrays 300 and 400 in Figures 3A-3C and 4A-4C). Each of the individual capacitors 136 in Figure 1H and individual capacitors 308 and 408 in Figures 3C and 4C, respectively can be connected to other components by extending the electrodes 104 (Figures 1H, 3C and 4C) to the peripheral edge 202 (Figure 2) of the capacitor array 100, 300 or 400.

Figure 6 is a schematic diagram of a memory device or system 600 in accordance with the present invention. The memory system 600 is an example of a system where a capacitor array similar to the capacitor array 504 of Figure 5 can be formed as part of an integrated circuit 502. The memory system 600 includes a plurality of memory elements 602 that can be arranged in rows and columns. Each memory cell 602 can include a transistor 604. Each transistor 604 includes a gate electrode 606 coupled to an address line 608 for controlling the operation of the memory cell 602, and each transistor 604 includes a first source/drain electrode 610 coupled to a data line 612 and a second source/drain electrode 614 coupled to a capacitor 616. The capacitor 616 can be similar to capacitors 126 (Figure 1H), 308 (Figure 3C) or 408 (Figure 4C) and the capacitors 616 for each of the memory cells 602 can be formed in an array similar to arrays 100, 300 and 400.

With reference to Figure 7, a semiconductor die 710 can be produced from a silicon wafer 700 that can contain an electronic system similar to the electronic system 500 of Figure 5 and the memory system 600 of Figure 6 including the novel capacitor 136 or capacitor arrays 100, 300 or 400 in accordance with the present invention. A die 710 is an individual pattern, typically rectangular, on a substrate that contains circuitry to perform a specific function. A semiconductor wafer 700 will typically contain a repeated pattern of such dies 710 containing the same functionality. Die 710 can further contain additional circuitry to extend to such complex devices as a monolithic processor with multiple functionality. Die 710 is typically packaged in a protective casing (not shown) with leads extending therefrom (not shown) providing access to the circuitry of the die 710 for unilateral or bilateral communication and control.

As shown in Figure 8, two or more dies 710, including at least one electronic system 500 or memory system 600 that incorporates the novel capacitor 136 or capacitor array 100, 300 or 400 in accordance with the present invention, can be combined, with or without a protective casing, into a circuit module 800 to enhance or extend the functionality of an individual die 710. Circuit module 800 can be a combination of dies 710 representing a variety of functions, or a



keyboard, pointing device, monitor and printer of a personal computer; the tuning dial, display and speakers of a radio; the ignition switch and gas pedal of an automobile; and the card reader, keypad, display and currency dispenser of an automated teller machine. User interface 1010 can further describe access ports  
5 provided to electronic system 1000. Access ports are used to connect an electronic system to the more tangible user interface components previously exemplified. One or more of the circuit modules 800 can be a processor providing some form of manipulation, control or direction of inputs from or outputs to user interface 1010, or of other information either preprogrammed into, or otherwise provided to,  
10 electronic system 1000. As will be apparent from the lists of examples previously given, electronic system 1000 will often contain certain mechanical components (not shown) in addition to the circuit modules 800 and user interface 1010. It will be appreciated that the one or more circuit modules 800 in electronic system 1000 can be replaced by a single integrated circuit. Furthermore, electronic system 1000  
15 can be a sub-component of a larger electronic system.

Figure 11 shows one embodiment of an electronic system as memory system 1100. Memory system 1100 contains one or more memory modules 900 as described above including the memory system 600 and capacitor 136 or capacitor array 100, 300 or 400 in accordance with the present invention and a memory  
20 controller 1110. Memory controller 1110 provides and controls a bidirectional interface between memory system 1100 and an external system bus 1120. Memory system 1100 accepts a command signal from the external bus 1120 and relays it to the one or more memory modules 900 on a command link 1130. Memory system 1100 provides for data input and data output between the one or more memory  
25 modules 900 and external system bus 1120 on data links 1140.

Figure 12 shows a further embodiment of an electronic system as a computer system 1200. Computer system 1200 contains a processor 1210 and a memory system 1100 housed in a computer unit 1215. Computer system 1200 is but one example of an electronic system containing another electronic system, i.e.  
30 memory system 1100, as a sub-component. Computer system 1200 optionally

contains user interface components. Depicted in Figure 12 are a keyboard 1220, a pointing device 1230, a monitor 1240, a printer 1250 and a bulk storage device 1260. It will be appreciated that other components are often associated with computer system 1200 such as modems, device driver cards, additional storage devices, etc. It will further be appreciated that the processor 1210 and memory system 1100 of computer system 1200 can be incorporated on a single integrated circuit similar to that discussed with respect to Figure 5. Such single package processing units reduce the communication time between the processor 1210 and the memory system 1100.

### **Conclusion**

The present invention thus provides a capacitor or an array of capacitors that maximizes the amount of capacitance and number of capacitors per unit of area of a semiconductor die or chip. The present invention also provides a capacitor or capacitor array that can be manufactured efficiently with minimal process operations. Additionally, the capacitor or capacitor array of the present invention can be manufactured on the same semiconductor die with other components and can be manufactured using process operations that are compatible with the manufacturing processes of other components and that do not interfere with other circuitry or components formed on the same die or chip.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiments shown. This application is intended to cover any adaptations or variations of the present invention. Therefore, it is intended that this invention be limited only by the claims and the equivalents thereof.